Minimizing and Managing Potential Impacts of Injection-Induced Seismicity from Class II Disposal Wells: Practical Approaches

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Acknowledgments

State Working Group Members

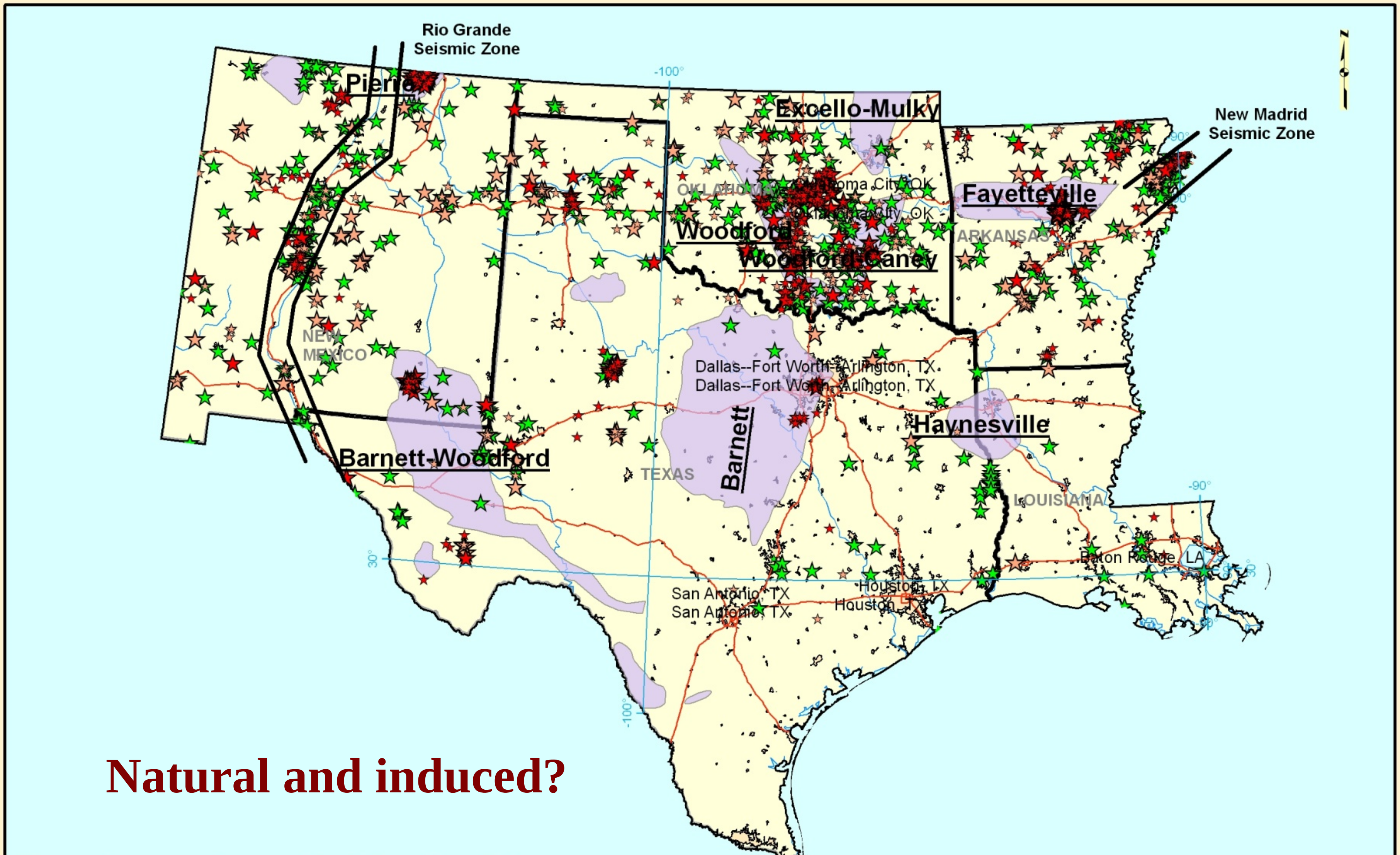
- Lawrence Bengal, Arkansas Oil and Gas Commission
- Douglas Johnson, Railroad Commission of Texas, retired
- Charles Lord, Oklahoma Corporation Commission
- James A Peterson, West Virginia Department of Environmental Protection
- Tom Tomastik ,Ohio Department of Natural Resources, retired
- Chuck Lowe, Ohio EPA
- Jim Milne, Colorado Oil and Gas Conservation Commission
- Denise Onyskiw, Colorado Oil and Gas Conservation Commission, retired
- Vince Matthews, Colorado Geologic Survey, retired

Expert Review Panel

- Brian Stump, Southern Methodist University
- Chris Hayward, Southern Methodist University
- Scott Ausbrooks, Arkansas Geological Survey
- Steve Horton, Center for Earthquake Research and Information, U of Memphis
- Ernest Majer, Lawrence Berkeley National Laboratory
- Norman Warpinski, Pinnacle
- John Satterfield, formerly with Chesapeake Energy
- Cliff Frohlich, University of Texas Institute for Geophysics,
- David Dillon, National Academy of Science
- Shah Kabir, Hess Energy
- Bill Smith, National Academy of Science, retired
- Roy Van Arsdale, University of Mephis
- Justin Rubenstein, USGS

Final Peer Review Panel

- Jeff Bull, Chesapeake Energy Corporation
- Robin McGuire, Lettis Consultants International, Inc.
- Craig Nicholson, University of California, Santa Barbara
- Kris Nygaard, ExxonMobil
- Heather Savage, Lamont-Doherty Earth Observatory, Columbia University
- Ed Steele, Swift Worldwide Services



Earthquakes & Shale Plays

Legend

>= 2000	1973-1999	1699-1973	
Magnitude	Magnitude		Urban Areas
0.0 - 3.0	0.0 - 3.0		Shale Gas Plays: EIA
3.1 - 5.0	3.1 - 5.7		

Albers Projection
Central Meridian: -96
1st Std Parallel: 20
2nd Std Parallel: 60
Latitude of Origin: 40

United States Environmental Protection Agency — Region 6

GROUND WATER CENTER

Covering Arkansas, Louisiana
New Mexico, Oklahoma & Texas

Presentation Summary

- Overview of Study Approach
- Discussion of engineering tools
- Summary of findings and recommendations

Overview of Study Approach

- Timeframe for effort
  - Earthquakes updated through 9/30/13.
  - References updated as of 5/23/14.

Overview of Study Approach

- Literature review and compilation
- Analysis of four case examples
- Development of decision model
- Fundamentals of induced seismicity
- Explore petroleum engineering methods

Overview of Study Approach

- Literature review and compilation
- Analysis of four case examples
- Development of decision model
- Fundamentals of induced seismicity
- Explore petroleum engineering methods

Overview of Study Approach

- Literature review and compilation
  - Peer reviewed material only
  - Comprehensive, but moving target

Overview of Study Approach

- Literature review and compilation
- Analysis of four case examples
- Development of decision model
- Fundamentals of induced seismicity
- Explore petroleum engineering methods

Overview of Study Approach

- Analysis of four case examples
  - Central Arkansas Area
  - North Texas Area
  - Braxton County, West Virginia
  - Youngstown, Ohio

Overview of Study Approach

- Analysis of four case examples
  - Geologic site summary
  - History of seismicity
  - State actions
  - Application of reservoir engineering methods
  - Lessons learned

Overview of Study Approach

- Literature review and compilation
- Analysis of four case examples
- Development of decision model
- Fundamentals of induced seismicity
- Explore petroleum engineering methods

Overview of Study Approach

- Development of decision model
  - Received much input throughout process
  - Comprehensive thought process - not specific
  - Founded on Director Discretionary Authority

DECISION MODEL FOR UIC DIRECTORS

Existing Class II

New Class II

UIC process ← Seismicity Concerns?

Site Assessment

Fault, Pressure buildup, Pathway

UIC process ← Remaining seismicity concerns?

Approaches

Monitoring, Operational, Management

Is there a satisfactory approach? → No permit

UIC process with conditions

Overview of Study Approach

- Literature review and compilation
- Analysis of four case examples
- Development of decision model
- Fundamentals of induced seismicity
- Explore petroleum engineering methods

Overview of Study Approach

- Fundamentals of induced seismicity
  - Captures a broader potential audience
  - Provides a general reference
  - Includes geoscience and engineering aspects

Overview of Study Approach

- Literature review and compilation
- Analysis of four case examples
- Development of decision model
- Fundamentals of induced seismicity
- Explore petroleum engineering methods

Presentation Summary

- Overview of Study Approach
- Discussion of engineering tools
- Summary findings and recommendations

Discussion of Engineering Tools

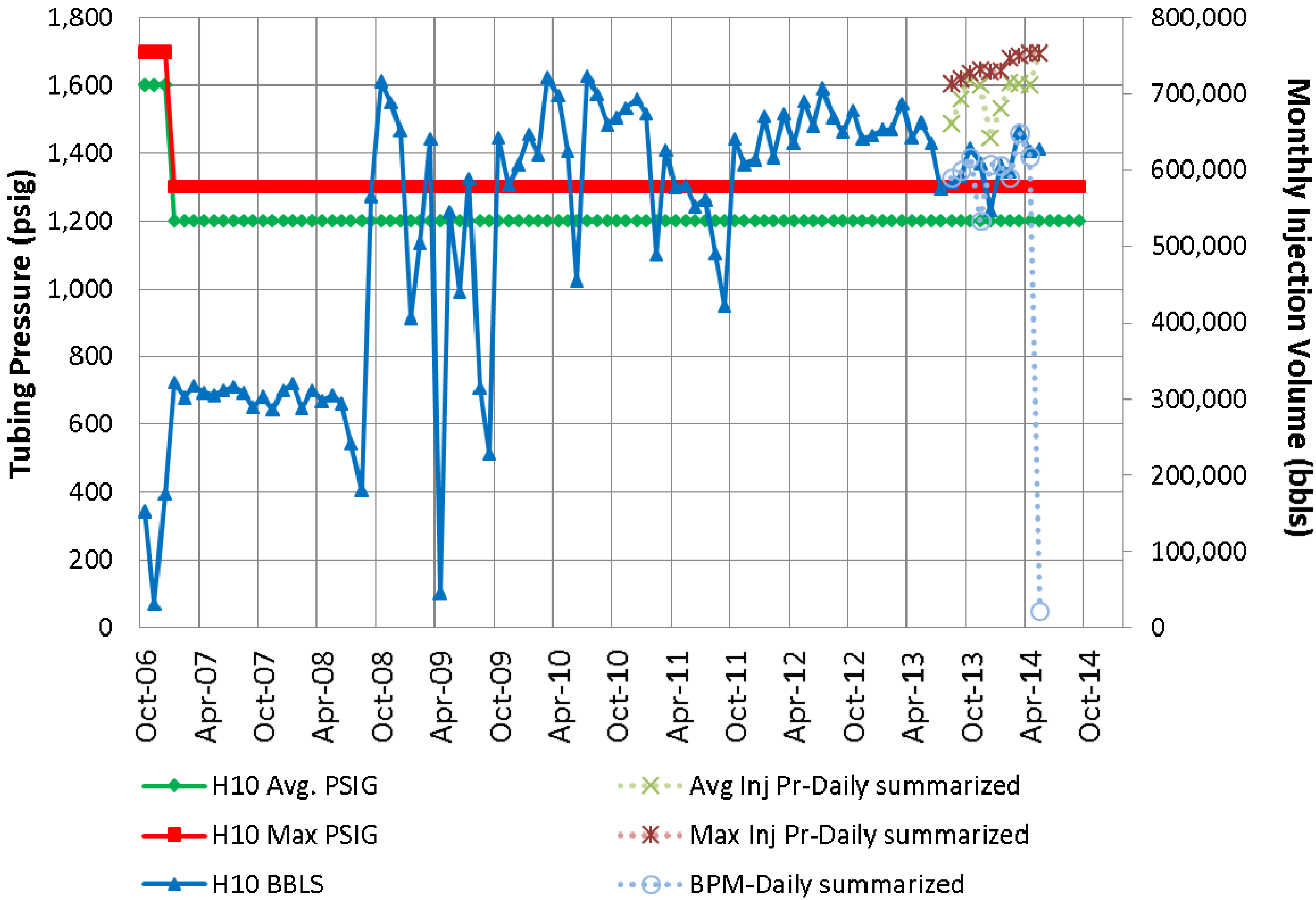
- A few points.
  - Quality of data is crucial.
  - These methods are an interpretive tool, not a fix-all.
  - Pressure buildup can be transmitted over great distances:
    - Multiple disposal wells in same formation and geographic area;
    - Individual wells in fracture flow dominated injection formations.
  - PE tools can determine if fracture flow is predominant.
  - PE tools can detect reservoir changes at distance, including faults.
  - Correspondence between well behavior and seismicity was apparent in some case example wells.

Discussion of Engineering Tools

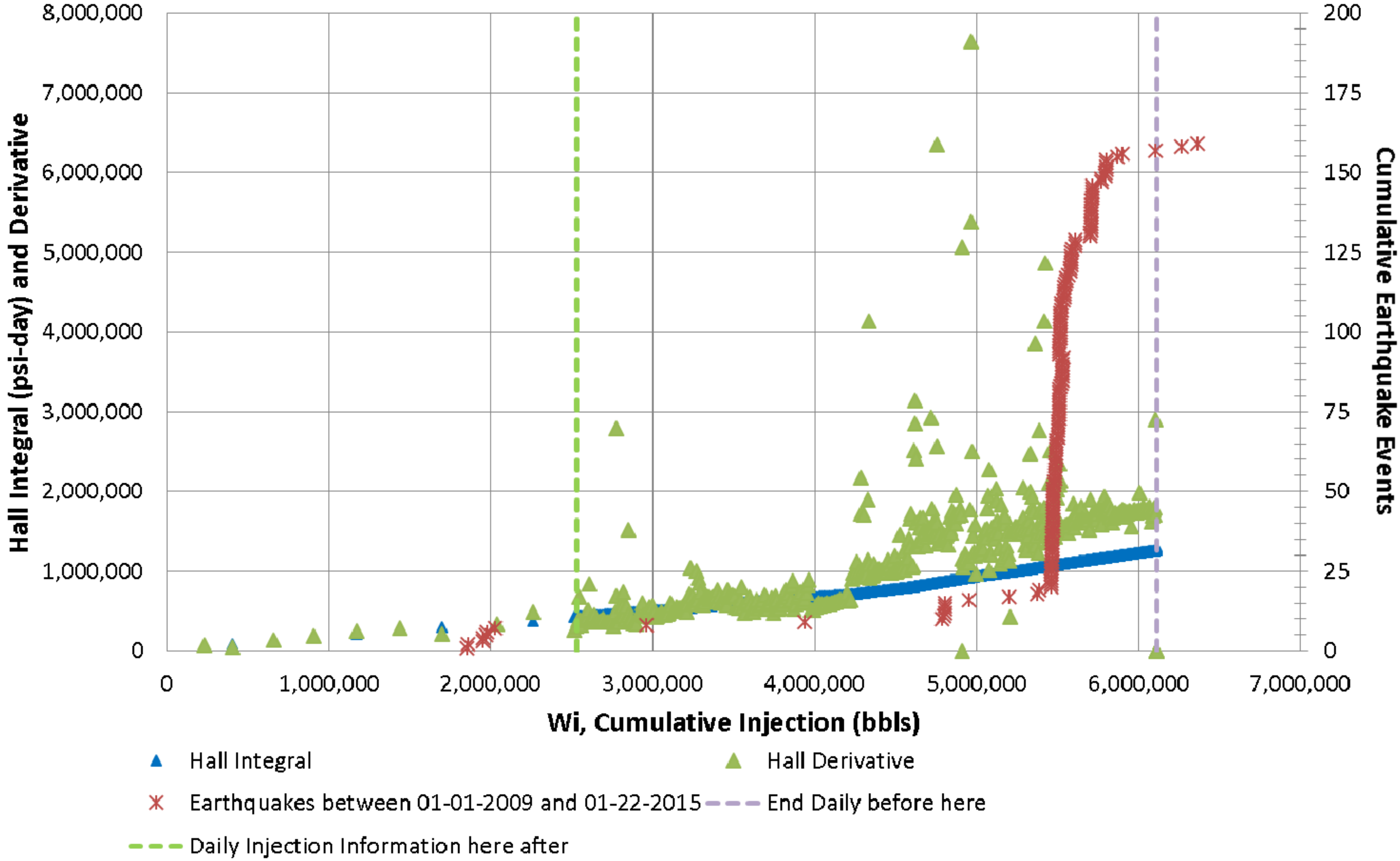
- Two fundamental approaches
  - Well testing
    - Pressure transient or falloff testing can determine if a reservoir is fractured, as well as static formation pressure.
    - Function of near well conditions.
  - Analysis of operational data
    - Hall plots using operational data (rates and pressures) indicate changes in transmissivity (ease of injection) at distance.
    - Covers both near wellbore and distance increasing with time.

Discussion of Engineering Tools

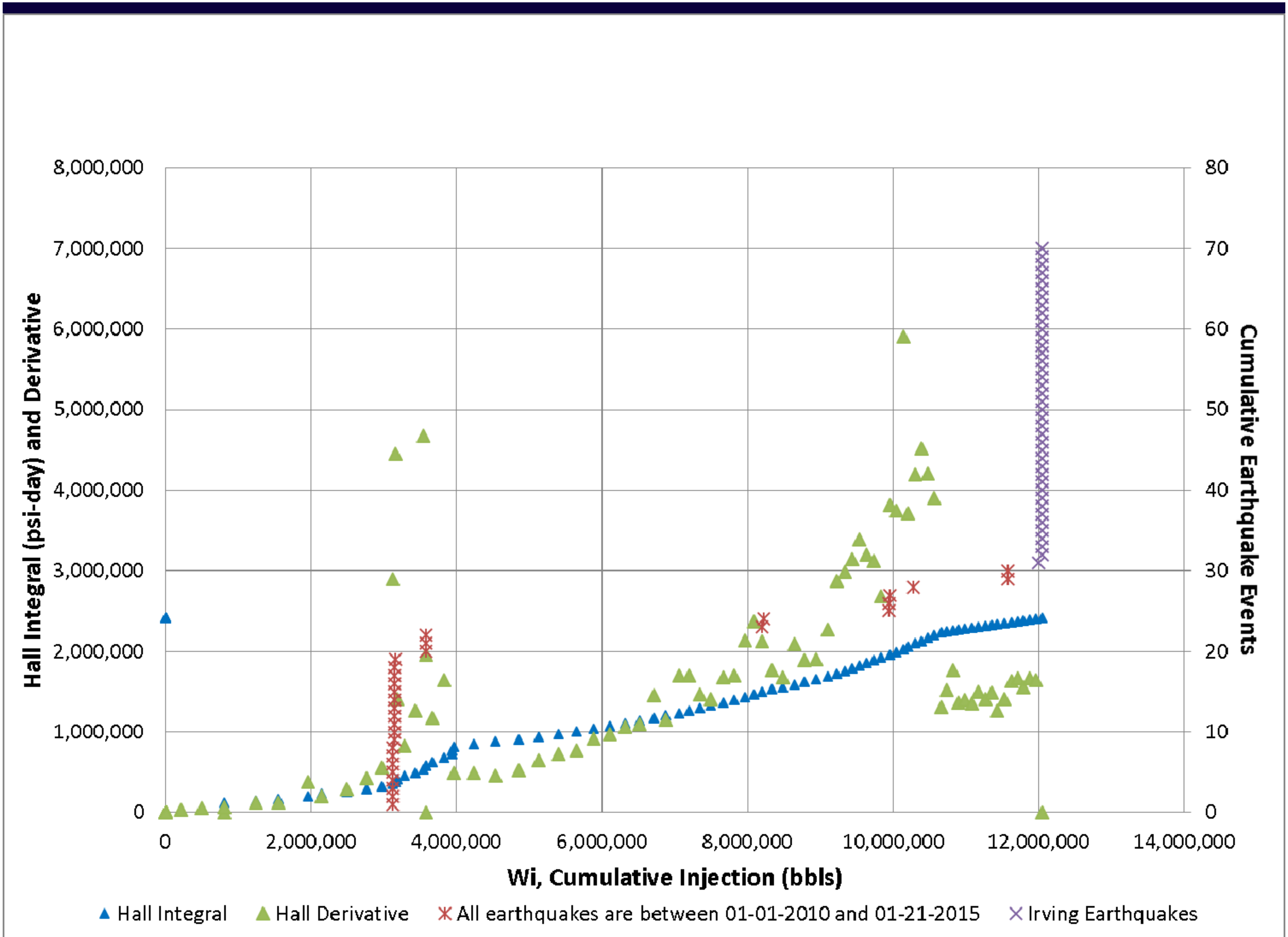
- Examples – operational data



Constant disposal or tubing pressures are probably not measured data.



Hall Integral (psi-day) and Derivative
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
200
175
150
125
100
75
50
25
0
Cumulative Earthquake Events
0
1,000,000
2,000,000
3,000,000
4,000,000
5,000,000
6,000,000
7,000,000
Wi, Cumulative Injection (bbls)
Hall Integral
Hall Derivative
Earthquakes between 01-01-2009 and 01-22-2015
End Daily before here
Daily Injection Information here after



8,000,000
7,000,000
6,000,000
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4,000,000
3,000,000
2,000,000
1,000,000
0
Hall Integral (psi-day) and Derivative
80
70
60
50
40
30
20
10
0
Cumulative Earthquake Events
0
2,000,000
4,000,000
6,000,000
8,000,000
10,000,000
12,000,000
14,000,000
Wi, Cumulative Injection (bbls)
Hall Integral
Hall Derivative
All earthquakes are between 01-01-2010 and 01-21-2015
Irving Earthquakes

Presentation Summary

- Overview of Study Approach
- Aspects of engineering tools
- Summary of findings and recommendations

Summary of Findings and Recommendations

- Take a proactive approach.
  - Realistic analysis instead of definitive proof.
  - Monitor seismicity trends in regional area.
    - Magnitude and frequency
  - Engage operators early.
    - Additional site geologic data
    - Voluntary actions
    - Increased operational data
  - Engage external expertise if warranted.
  - Modify operations if warranted.

Summary of Findings and Recommendations

- Perform multi-disciplinary characterization of site (injection reservoir testing, analysis, consultation, literature).
- Case examples – deep fractured reservoirs.
    - Fractures more likely to communicate pressure buildup long distances.
    - Buildup can be directional and extend miles.
    - Fractured reservoirs can result in communication with basement rocks, lower confining strata is important.

Summary of Findings and Recommendations

- Assure high quality operational data.
- Permitting contingencies (traffic light approach) are an excellent tool to address site uncertainties.
- Increased seismometers better define seismic activity.

Final Words

- http://www.epa.gov/region5/water/uic/ntwg/pdfs/induced-seismicity-201502.pdf
- EPA Region 6 is preparing a seismicity training module for injection well regulators.
- We have a summary poster set up.

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Purpose

Provides the UIC Director with tools for minimizing and managing induced seismicity on a site-specific basis, using available Director discretionary authority.

The authority used to address potential USDW risks from seismic events could include:

- Loss of disposal well mechanical integrity;
- Impact to various types of existing wells;
- Changes in USDW water level or turbidity;
- USDW contamination resulting from fluid movement through faults, wellbore damage, or earthquake-damaged surface sources.

National Technical Workgroup Tasks

1. Compare parameters identified as most applicable to induced seismicity with the technical parameters collected under current regulations.
2. Prepare a decision model.
3. Assess applicability of pressure transient testing and/or pressure monitoring techniques.
4. Summarize lessons learned from case studies.
5. Recommend measurements or monitoring techniques for higher risk areas.
6. Analyze applicability of conclusions to other well classes.
7. Recommend specific areas for further research needed.

Critical Components

Pressure buildup	Faults of Concern	Pathway
• An increase in the formation pore pressure from disposal activities.	• Optimally oriented for movement, and under critical stress. • Sufficient size for movement to potentially cause a significant earthquake. • May be a single fault or a zone of multiple faults and fractures.	• A permeable avenue (matrix or fracture permeability) allowing the pore pressure increase to reach the fault.

Decision Thought Process

Existing Class II → Seismicity Concerns? ← New Class II

UIC Process ← Seismicity Concerns?

↓

Site Assessment
(Fault, Pressure Buildup, Pathway)

↓

UIC Process ← Remaining Seismicity Concerns?

↓

Approaches
(Monitoring, Operational, Management)

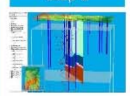
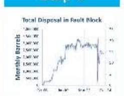
↓

Is There A Satisfactory Approach? → No Permit

↓

UIC Process With Conditions

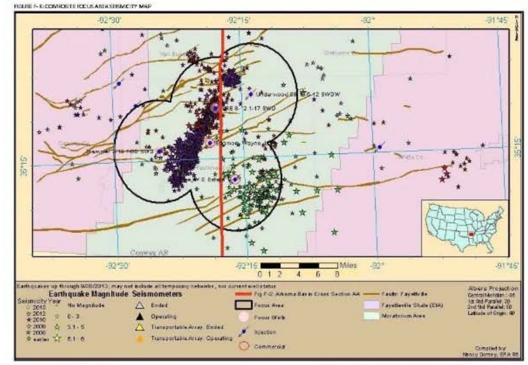
Work Flow and Action Plan

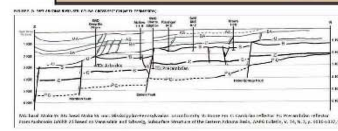
Step 1	Step 2	Step 3	Step 4
			
Collect necessary data	GIS Mapping and Analysis	Can the potential be mitigated?	Act in a timely fashion

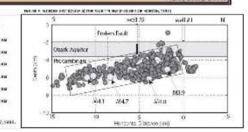
Multi-Disciplinary Site Assessment

Information Needed	Source
Regional and Local Seismicity	USGS or state agency catalog; event accuracy, seismometer spacing
Detailed Well Information	Permit and other well files, including daily disposal volumes and pressures
Geologic Setting	Maps, cross-sections, permit application, seismic surveys, publications
Reservoir Characterization	Core analysis, well tests, well logs, hydraulic fracture results, publications
Reservoir Pressure	Static pressure: gauge or fluid level
Flow Character	Analysis or modeling
Pathway	Analysis or test results
Stress Direction	Borehole breakout, production logs

Site Example



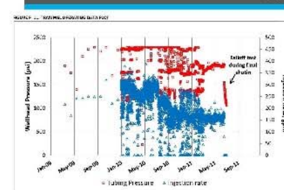


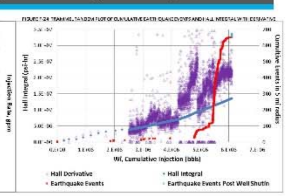


The Director acquired additional site information, requested action from operators, and prohibited disposal operations. Specific examples include:

- Increased monitoring and reporting requirements for disposal well operators to provide additional operational data for reservoir analysis.
- Required one well to install a seismic monitoring array prior to disposal as an initial permit condition.
- Required plugging or temporary shutin of suspect disposal wells linked to injection-induced seismicity while investigating or interpreting additional data.
- Defined a moratorium area prohibiting Class II disposal wells within a defined high risk area of seismic activity.

Petroleum Engineering Analysis





Report Conclusions

- Be proactive rather than requiring definitive proof.
- Utilize multi-disciplinary approaches.
- Understand that pressure can be transmitted miles through fractures.
- Apply established engineering tools using high quality data.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY